Monitoring Strategies for Evaluating Non-target Effects: and Predicting Secondary Effects *a priori*.

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The introduction or augmentative application of pathogens in the environment holds similar benefits and risks to other types biological control agents that are used for pest control. All of these organisms can help control severe pest invasions but also have the potential to cause disruption to natural or manipulated ecosystems. Although I believe the risks of side effects are small compared to the large negative impacts caused by many invasive pest species, care must still be taken when conducting microbial control programs in order to avoid or limit non-target impacts. This process should begin when invasive pests are first identified as potential targets for biological control, and continue on throughout the process of agent selection, development and application. Proper pre-release assessment is essential and should follow the general procedures as developed by the biological control community and regulatory agencies.

Benefit/ Risk Assessment should be at the heart of every biological control program, to ensure that the pest control solution is worth all potential monetary and environmental costs. Most programs follow such guidelines, but regulatory decisions are often made without full knowledge of all the benefits or all the risks involved. It is hard and probably impossible to know and evaluate all the potential interactions and outcomes that may be involved, especially in complex natural ecosystems. Host specificity testing and efficacy evaluations have been the mainstay of evaluation in most contemporary biological control efforts. These studies help to provide information on the direct impacts of the natural enemy on the targeted invasive species and also can provide further insights on other organisms that may be at risk in the release or augmentation environment. Regardless of testing and evaluation, some risk is inherent in the use of biological control, as it is in every method of pest control. Even when some non-target impact are know and deemed acceptable, it is usually necessary to continue assessment on into actual field operations to help predict unexpected non-target impacts and then to actually measure such effects under real world conditions, if they occur.

Secondary effects are considered to be all impacts beyond those caused directly to the target organism. If a natural enemy is not host specific, additional direct affects can be caused to other non-target host populations. However, many indirect impacts, can also be caused by adding species to a food-web or just through raising population levels to abnormally high densities through augmentation. By only altering pest densities, secondary effects on associated species in the ecosystem have often been observed. Such effects can range across many trophic levels of an ecosystem by altering flow patterns and/or critical interaction rates. Indirect impacts that carry throughout food-webs may have a variety of effects, some of which may be positive, while other effects may have neutral or negative implications. Interpretation of these effects often depends upon the perspective of the assessor, further making the task of regulation difficult. A number of recent studies have assessed species additions in various ecosystems and have identified potentially negative biological control impacts, including species displacements, alteration of population densities (up and down), and have detected cascading effects that change food-web

linkages or alter key demographic rates. Others have assessed the impact of parasitism, predation and disease causing organisms on agricultural and natural communities, including the effect of biological control introductions. Recently, food-web modules have been used to, describe, simplify and study biological control introductions. Such studies have demonstrated how biological control agents can cause indirect effects in ecological communities. Most studies, however, have been retrospective in nature and have concluded that indirect non-target impacts are very difficult to predict, especially if they cascade through multiple levels of existing food-webs, or if new food-web linkages are made where not expected.

Additionally, changes in both habitat structure and function linked with changing climate, or the addition of other invasive (or replacement) species, makes community level prediction of biological control interventions difficult and short-term at best. Quantitative modeling has been used to make predictions about species additions both in natural and managed ecosystems. However, the models used, typically lack the necessary structural detail or dynamic process-oriented functions to accurately predict direct target impacts, and are even less accurate in predicting non-target effects. Research in this area is expanding (see www.foodweb.org), however better tools are needed for predictive assessment of biological control systems. Thus *a priori* prediction of indirect impacts of biological control is still not dependable unless the system is very simple in structure and function.

Despite the uncertainty, the field of biological control moves forward with careful regulatory oversight, often backed by ecological monitoring to assess both target and non-target impacts. Monitoring of biological control release efforts are typically conducted for the short-term but are poorly funded to continue in the long-term, despite the scientific and regulatory desire for such studies. A review of the monitoring literature provides insights and advice on developing and implementing monitoring efforts for biological control. Some of the most salient suggestions are: Monitoring programs should not be conducted "just to meet regulatory requirements", and most importantly should be designed and supported by scientific-based hypotheses linked with specific project goals. Good monitoring programs should be properly designed, based on a structural and functional understanding of the populations, communities and ecosystem that is being targeted. They should avoid collecting a laundry list of data without purpose and once collected the data needs to be actively assessed, evaluated and shared with the scientific and regulatory communities.

Many different techniques are available to implement monitoring programs, but the best programs are typically based on formulating a limited number of effective scientific questions or hypothesis, having an accurate and robust underlying conceptual model of the system of interest. Selection of appropriate populations and processes to measure, which also must be accurately assessed using appropriate sampling techniques. Such assessments must be done within an appropriate sample universe, over a wide enough area to be representative of the systems as a whole. In doing so it is mandatory to apply an appropriate statistical designs with appropriate control areas for comparison. Effective monitoring programs have well developed partnerships among key cooperators with strong leadership to help maintaining adequate funding, while at the same time following an adaptive monitoring framework that can be adjusted as needed. More often than not, effective monitoring efforts are directly linked with experimental studies to test specific hypotheses and to promote open dialog on critical issues.